QUANTITY TAKE-OFF IN MODEL-BASED SYSTEMS

Can Ersen Firat, PhD Candidate, Researcher , canersen@cc.hut.fi
Construction Management and Economics, Aalto University School of Science and Technology; Aalto, Espoo, Finland
David Arditi, Professor and Director, arditi@iit.edu
Construction Engineering and Management Program, Illinois Institute of Technology, Chicago, IL, USA
Juho-Pekka Hämäläinen, Project Manager, juho-pekka.hamalainen@skanska.fi
Skanska BIM Competence Center, Skanska Oy, Finland
Johan Stenstrand, BIM Engineer, johan.stenstrand@skanska.fi
Skanska BIM Competence Center, Skanska Oy, Finland
Juhani Kiiras, Professor, juhani.kiiras@tkk.fi
Construction Management and Economics, Aalto University School of Science and Technology; Aalto, Espoo, Finland

ABSTRACT

In recent years, as Information Technology (IT) tools and Building Information Models (BIM) are adopted by more practitioners, it has become apparent that it is possible to have a faster and more efficient quantity take-off system. The efficiency of quantity take-off lies in the smart transfer of the information produced in the design process to construction. Existing BIM-based quantity take-off is performed in the design phase of a project. BIM-based systems provide a smart platform for information exchange between design and construction.

A "model-based" system refers in this paper to a Building Construction Information Model (BCIM) coupled with a location-based scheduling process. BCIM offers an environment in the construction phase, where data are stored, updated, and reused via the evolving project libraries of a building contractor. BCIM is composed of three sub-models: (i) a building product model that provides the sections and quantities, (ii) a building resource and cost model that provides activity lists and labour consumptions to calculate activity durations, and (iii) a building process model that introduces the interdependencies of the activities. In the location-based scheduling process, a preliminary master schedule is obtained automatically from an information database, and then improved by the planner to fit the conditions of the company and of the project. The use of Advanced Line of Balance (ALoB) is proposed in location-based scheduling.

The objective of this paper is to introduce the principles involved in quantity take-off in a "model-based" system as implemented by a contractor. The paper consists of three parts: (1) the "model-based" system (composed of BCIM and ALoB) is introduced as the theoretical background; (2) the steps in performing quantity take-off in "model-based" systems are described; and (3) Two residential construction projects are used to test the proposed quantity take-off principles.

Keywords: building information modeling, BIM, model-based systems, location-based scheduling, quantity take-off

1. INTRODUCTION

There has been a gap between designers and production teams in the use of Information Technology tools. However the latest developments in software technology and the fast adoption of the building information modeling (BIM) concept by practitioners has provided construction professionals with invaluable benefits. One of the key elements of this development is a faster and more efficient quantity take-off system.

Calculating the quantities of production is essential for effective cost estimating, cost control, project scheduling, and thus for project management. Quantity take-off is the tallying of components from printed drawing sets or more recently from CAD drawings. In the current practice this quantification process is done mostly manually from 2D drawings. This process is complex and is prone to human error because of technological as well as organizational problems. Project efficiencies and the accuracy of schedules are dependent on realistic and reliable quantity take-off. The automation of the quantity take-off process by using the current advances in IT, can provide a solution to these problems. Indeed, BIM-based systems provide a smart platform for information exchange between design and construction, which in turn provides an efficient environment for flawless quantity take-off. A "model-based" system refers in this paper to a Building Construction Information Model (BCIM) coupled with a location-based scheduling process. Scheduling is one of the core functions of project management. For feasible schedules, reliable data are needed. BIM provides this data repository as well as the information flow for location-based scheduling. For example, the bill of quantities is created within BCIM in terms of location-based quantities. Location-based scheduling is preferred in this study because it is suitable for scheduling building projects that are composed of repetitive activities even if the quantities involved in these activities are different in different locations (e.g., Arditi et al., 2002; Kenley and Seppänen, 2010). Location-based scheduling is widely used in Finland. BCIM and location-based scheduling are described in the next two sections.

The objective of this paper is to introduce the principles involved in quantity take-off in a "model-based" system as implemented by a contractor. The paper consists of three parts: (1) the "model-based" system (i.e., BCIM) is introduced as the theoretical background; (2) quantity take-off in "model-based" systems is described; and (3) two residential construction projects are used to test the proposed quantity take-off principles.

2. MODEL-BASED SYSTEMS

In line with Eastman et al.'s (2008) definitions, the BIM concept adopted in this research involves not only a virtual model of a building, nor only the information modeling activity, but a whole information modeling process with interactive human users storing data in libraries and updating them periodically. The focus is on the production phase, so the letter "C" for construction is inserted into BIM, making it BCIM, the Building Construction Information Model. BCIM is a dynamic, changeable library-based information model that uses commercial software to allow the semi-automatic, partly interactive generation of design and production information such as drawings, specifications, bills of quantities, cost estimates, budgets, schedules, procurement plans, and status reports.

As seen in Figure 1, BCIM is composed of three sub-models: a building product model (BPM), a building resource and cost model (BRCM), and a building process model (BPrM). The building product model (BPM) targets the finished building as a set of interdependent design objects, i.e., spaces, building elements, and their product structures at a minimum. Generic building elements structures are stored and updated and reused via building elements library. The building resource and cost model (BRCM) targets the building project as a set of interdependent resource objects, i.e., the amounts of building products (retrieved from the BPM) and their resource structures or receipts, with current prices, planned to be exploited for the manufacturing and installation of these building products. Generic resource structures and prices are stored, updated, and reused via a resource structures library. The building process model (BPrM) targets the building project as a set of interdependent activity objects, i.e., tasks that are coupled with their resource structures (retrieved from the BRCM) and resource based rules for calculating activity durations. Generic building project activities, their planning rules, and interdependencies are stored, updated, and reused via an activity structure library (Firat et al., 2008).

"Model-based" scheduling is a computer aided scheduling technique that automatically processes information retrieved from information models and creates a dynamic scheduling platform (Firat et al., 2009b). Firat et al. (2009a) suggest that model-based master scheduling can be performed by integrating Building Information Modeling (BIM) and Advanced Line of Balance (ALoB) with the input of an interactive planner. The Line of Balance (LoB) method is a graphical scheduling technique and a location- and resource-based management system to plan and manage continuous work flows in specified locations with balanced resource use. Kenley and Seppänen (2010) investigate LoB in the context of location-based management systems. Advanced Line of Balance (ALoB) differs from the traditional LoB in that the sections (e.g., floors of a building) need not be equal in size or same in their activity content. In a time-location diagram, the workflow of each activity is shown through the sections of a project (Firat et al., 2009a). Firat et al. (2009b) discuss the use of ALoB in model-based scheduling thoroughly. For reliable schedules, effective quantity take-off systems have to be established.

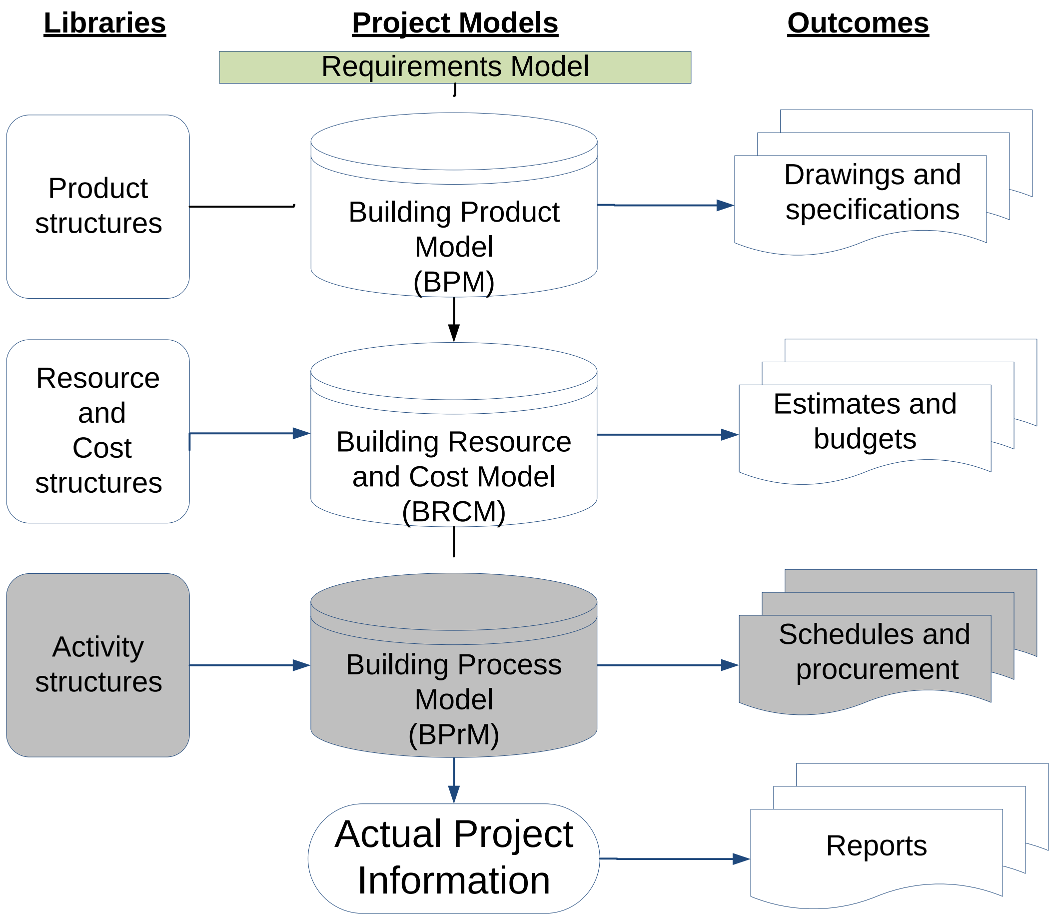

Figure 1: BCIM

BIM is quite popular in Finland (e.g., RATAS; Björk, 1994) and it is even extended to renovation projects (e.g., Andersin, 2010). Senate Properties, an enterprise under the Finnish Ministry of Finance that provides property services to customers in the Finnish government, have in cooperation with their international partners provided requirements for the use of BIM in their construction projects. The BIM requirements, require the use of IFC standards (Industry Foundation Classes) in all major projects since 1 October 2007 (Senate Properties, 2007). The IFC is a non-proprietary object based building data model, making it possible for vendors to create their own import and export applications to handle IFC files, hence enhancing the interoperability between different BIM tools (Stenstrand, 2010).

3. MODEL-BASED QUANTITY TAKE-OFF

Quantity take-off is the backbone of production management and provides crucial information for scheduling. This section discusses quantity take-offs in model-based systems implemented by a contractor.

According to Stenstrand (2010), quantity take-offs are currently performed at Skanska Construction Services by site managers and project engineers for ordering materials. In the current practice, the quantities are calculated by hand from paper drawings and documented on paper or on Excel spreadsheets. The bills of quantities produced by cost estimators at the earlier stages of the project are used to compare the estimated quantities with the ones measured on site. This kind of pre-BIM practice is quite inefficient.

In a BIM environment too, quantity take-offs are performed several times during the project. Figure 2 illustrates the process flow of quantity take-off during the design and construction phases of the life cycle of a project. A rough cost estimate called a parametric estimate is made at the inception or early design phase of a project when the needs and objectives are barely available. A space plan and a requirements model are created early in the project with information like spaces and activities (Haahtela and Kiiras, 2008). After a rough cost estimate is obtained that sets the target price, a BCIM is developed and quantity take-off is performed a second time for a detailed cost estimate. This cost estimate is used by the contractor to develop the offer made to the construction owner. The third time where the quantity take-off process is performed is on site, during actual construction. The earlier the quantity take-off is performed, the less detailed and the less accurate the cost estimate will be.

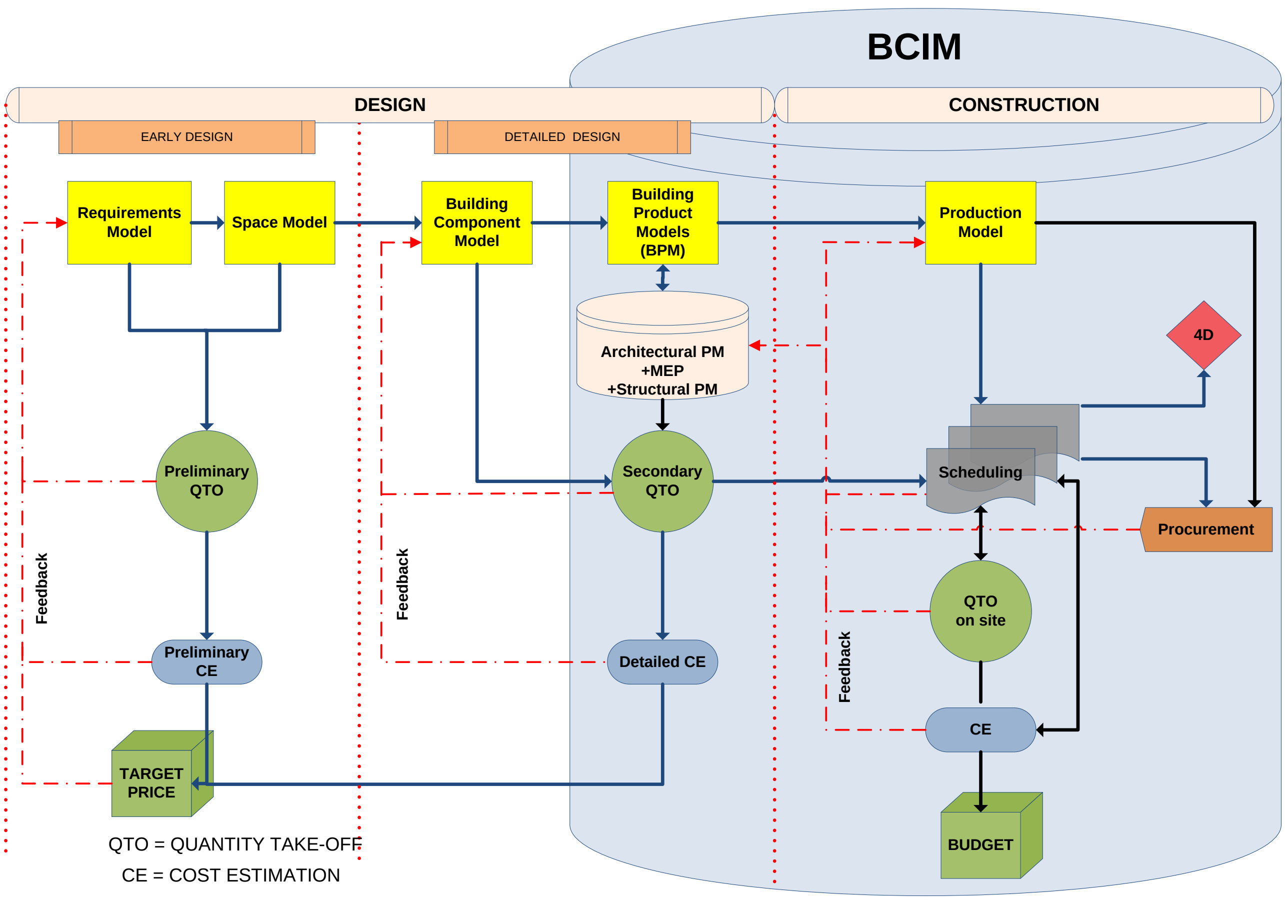

Figure 2: Process flow of quantity take-offs during life cycle of a project.

Classification systems constitute the backbone of effective model-based quantity take-off. Classification systems differ greatly from country to country, such as MasterFormat in the U.S. (Gulledge et al., 2007) and Building 2000 used by architects and Building 80 used by builders in Finland. Building 2000 is generally favored because it supports BIM (Knopp-Trendafilova, 2010).

4. TWO CASE STUDIES

The first case is a residential building project in Finland. The project consists of two separate buildings of four stories each with a total of 44 apartments. The common facilities and storage rooms are located in the basement and the parking garage is located on the ground floor. The structural system is composed of reinforced concrete components. The gross area of the buildings is 4,226 m^2 and the building's volume is 14,280 m^3. An illustration of this project is presented in Figure 3. The project was used as a pilot project in the use of BIM through all phases of the project. The architectural details were modeled in ArchiCAD, the structural system in Tekla Structures, and the HVAC system in MagiCAD. Clash detection and other checks were performed by Solibri Model Checker. For construction site management, the models were then combined in Tekla Structures' CM module by importing the architectural, electrical, and HVAC files in IFC format. On the construction site, Tekla Structures was used for building a site plan, a work schedule, visualization, 4D modeling, and quantity take-off (Stenstrand, 2010).

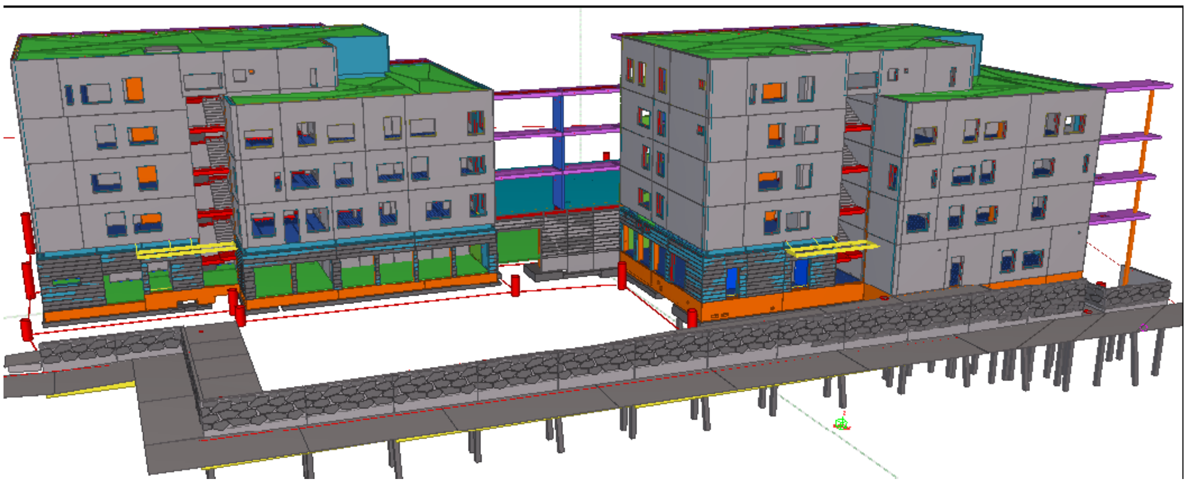

Figure 3: Illustration of Case 1

Stenstrand (2010) reports that the experience of quantity take-off in the case study was mostly smooth. However, the quantity take-off obtained was not considered to be reliable enough for use as the only source of information for ordering materials. Therefore model-based quantity take-off was used only as a complementary method to the traditionally performed quantity take-off from 2D drawings. The new CM module of Tekla Structures is a promising BIM tool for construction site managers, but it is still in its infancy and therefore not yet completely suitable for construction site management. Another reason of the low performance of model-based quantity take-off was the classification system used, i.e., Building 80. The newer classification system Building 2000 is more suitable for use with BIM, but it has not yet been adopted by construction contractors in Finland.

This case study has also revealed some basic guidelines for the contractor about the use of BIM: (1) the model must correspond to the actual design, which means that the model must be constantly updated; (2) the model should be constructed in a way that allows quantity take-off, which means that the naming of components must be done according to instructions, there cannot be any clashes, objects have to be modeled with the right tools, etc.; and (3) the project participants, i.e., the structural engineer, the owner, and all other stakeholders who are dependent on quantity take-offs must agree on the level of detail in the model. Likewise, some issues to be taken into account were also highlighted when performing quantity take-offs using BIM: (1) the reports list only the information that is modeled in the building model, which means that the detail of the model must be high enough to produce valuable quantity take-off reports; (2) all quantity take-off reports generated by the model should be checked; and (3) well defined calculation rules must be in place (Stenstrand, 2010).

The second case project is also a residential building in Finland. The project consists of a five-story building of 18 apartments. The gross area of the building is 1,732 m^2 and the building volume is 5,550 m^3. The BIM configuration is similar to the one in the first case: the architectural details were modeled in ArchiCAD, the structural system in Tekla Structures, and the HVAC model in MagiCAD. The models were checked with Solibri Model Checker and Tekla Structures was used on site for production planning.

The quantities were taken-off from the architectural model and transferred to a location-based cost estimate by using Tocoman iLink or a spreadsheet. Linking the model information with the cost estimate gave an accurate location-based cost estimate for the project. The cost estimate was then exported to VicoControl (Vico; Software links, 2010). A location-based bill of quantities provided reliable information to the project manager for creating the master schedule. The project manager started creating the schedule keeping in mind the target duration of the project, and by combining the durations and the sequence of the activities. The durations of activities were calculated by making use of the bill of quantities (Firat et al., 2009b).

This case study showed that it is possible to develop master schedules in a model-based (BCIM) environment and that this activity is enhanced by a location-based bill of quantities generated by a quantity take-off routine associated with BCIM. Figure 4 shows the comparison of the model-based schedule versus a traditional schedule in the second case. The analysis of the model-based schedule is beyond the scope of this paper.

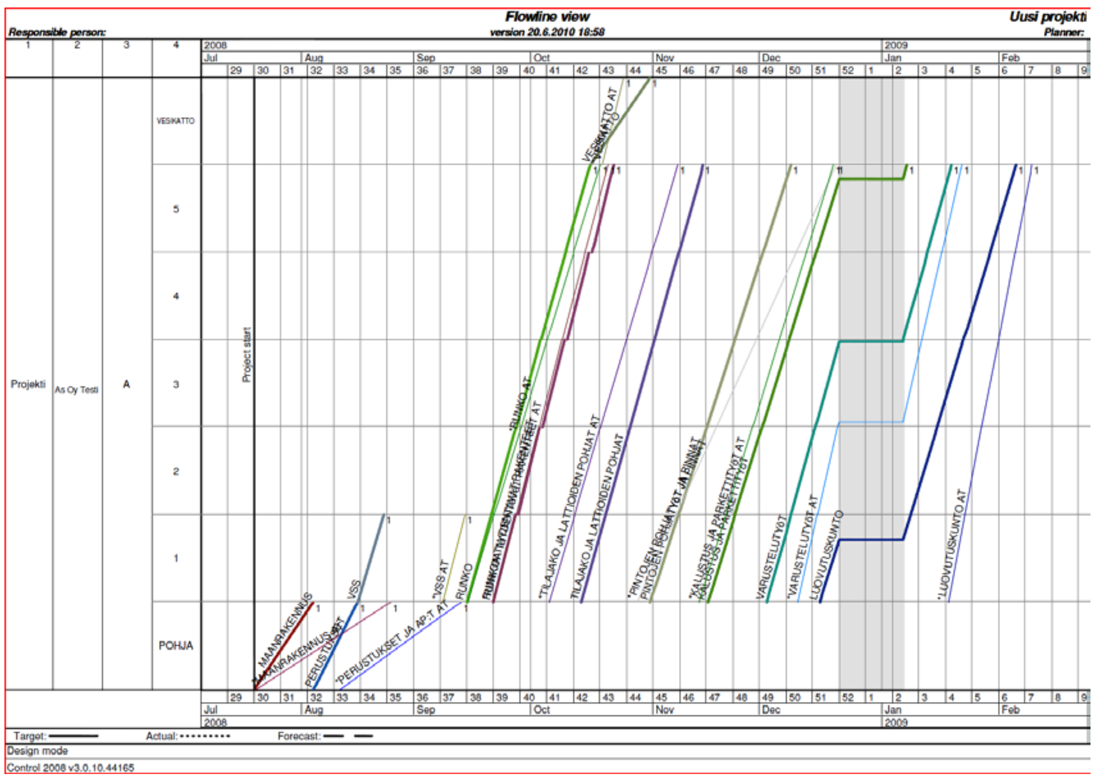

Figure 4: Model-based schedule versus the traditional schedule in Case 2

The case studies revealed that the main problems and challenges associated with quantity take-off in model-based systems can be summarized as: (1) resistance to change (i.e., transition to model-based quantity take-off) by project participants, (2) the suitability of classification systems into BIM applications, (3) determination of the level of detail of the building models in different project phases, (4) data exchange between BIM and quantity take-off (e.g., Application Program Interface - API, Industry Foundation Class - IFC). However, there are commercially available software such as Innovaya Visual Quantity Take-off (QTO), Vico Take-off Manager, Tocoman iLink (see Software links, 2010) that support standard BIM software. These packages provide valuable solutions to technical problems, but a new mindset needs to be promoted through extensive instruction and training in order to cope with organizational and human challenges.

5. CONCLUDING REMARKS

This study addresses an important issue in model-based management: quantity take-off. A quantity take-off is used to develop cost estimates in the early stages of a project, a work schedule at the start of a project, and a bill of quantities that can be used for ordering materials later in the project. The purpose of this paper is to explore quantity take-off processes in model-based systems. A literature review about model-based systems reveals that there has been significant improvement in developments and growing interest in the adoption of model-based systems. In this fast growing field, quantity take-off occupies an important place.

Model-based scheduling combines BCIM alongside location-based scheduling with the input of an interactive planner. Location-based quantities calculated as a result of BCIM-supported quantity take-off systems feed into the scheduling process.

Two case studies were performed. The first case examined how BIM can be utilized in quantity take-off within a construction company for on-site purposes and to test a BIM tool called Tekla Structures' CM module for model-based quantity take-off. The second case study was performed to check the possibility of using model-based quantity take-off to create model-based schedules. The first case study showed that the largest obstacle to model-based quantity take-off for site use was the lack of design control and modeling guidelines. This is because the level of detail is bigger on site, whereas in the estimation phase estimators can do with less detail to evaluate the quantities. It was also found that classification systems constitute the most critical factor in model-based quantity take-off. In both case studies, Tekla Structures' CM tool has proved to be promising but so far its use has been limited. The findings of the case studies are specific to building projects, but can be extrapolated to other types of projects.

In conclusion, to be effective, a model should be constructed in such a way that quantity take-off is possible and easy. The level of detail should be determined by all participants involved in a project. Guidelines for model-based quantity take-off are also most welcome. By further testing Tekla Structures' CM module in more case studies, the confusion experienced by users can be minimized. It is clear that model-based master schedules can be developed more easily if the system produces location-based quantities. The trends look promising and model-based quantity take-off can be made easier and less confusing to use by further testing it in more case studies.

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